High-Resolution Measurement-Based Phase-Resolved Prediction of Ocean Wavefields

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LONG-TERM GOAL

Given remote and direct physical measurements of a realistic ocean wavefield, obtain a high-resolution description of the wavefield by integrating the measurements with direct phase-resolved wave computations including realistic environmental effects such as wind forcing and wave breaking dissipation. Inform and guide the measurements necessary for achieving this reconstruction and address the validity, accuracy and limitations of such wavefield reconstructions.

OBJECTIVES

The specific scientific and technical objectives are to obtain:

1. Development of a phase-resolved, deterministic prediction capability for nonlinear wavefield reconstruction and evolution at intermediate scale (O(1) ~ O(10)km) using ship-mounted radar wave measurements
2. Incorporation and evaluation of physics-based wind-forcing and wave-breaking models that are developed/calibrated/validated based on simulations and measurements
3. Characterization and quantification of uncertainty and incompleteness in sensing data on wavefield prediction
4. Direct comparison between quantitative field/laboratory measurements and nonlinear wavefield reconstruction and prediction
5. Development of a theoretical/computational framework for wavefield reconstruction and predictability that can guide deployment of wave sensing systems and data interpretation

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14. ABSTRACT
Given remote and direct physical measurements of a realistic ocean wavefield, obtain a high-resolution description of the wavefield by integrating the measurements with direct phase-resolved wave computations including realistic environmental effects such as wind forcing and wave breaking dissipation. Inform and guide the measurements necessary for achieving this reconstruction and address the validity, accuracy and limitations of such wavefield reconstructions.

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APPROACH

We develop and apply a comprehensive deterministic model for intermediate scale, O(10)km, wave environment prediction by integrating whole-field and multiple-point direct measurements of the wave and atmospheric environment with nonlinear simulation-based reconstruction of the wavefield. The wave reconstruction is based on phase-resolved simulation of nonlinear surface wave dynamics, and utilizes hybrid (from different types of sensors) measurements that may contain noise, uncertainty and gaps. The simulations also incorporate physics-based wind forcing and wave-breaking dissipation models, which are themselves developed/validated/calibrated based on measurements.

Nonlinear wavefield reconstruction is based on an iterative optimization approach using multilevel phase-resolved wave models of different nonlinearity orders. Specifically, for low-level optimization which is sufficient for mild waves, the theoretical linear and second-order Stokes solutions are used. For high-level optimization which is required for moderately steep waves, an efficient nonlinear wave simulation model based on the high-order spectral method is employed. Once the wavefield is reconstructed, its future evolution is given by wave models using the reconstructed wavefield as an initial condition (Wu 2004). In wave modeling, wind forcing is included through a pressure distribution on the free surface and wave-breaking dissipation is considered by an effective low-pass filter in spectral space.

WORK COMPLETED

In the first year of the project, we focus on the development and improvement of the deterministic nonlinear wave reconstruction capability involving hybrid (radar and probe) wave data and performance tests of the capability using sample field radar wave data. Specifically, the following work is completed:

- **Development of high-resolution wave reconstruction and prediction capability:** We extend the present reconstruction capability for discrete point wave data to include the presence of radar sensed wave data. In particular, we focus on the understanding of wavefield's predictability (in spatial-temporal domain) based on given radar sensed wave data.

- **Characterization/quantification of the effects of noise, uncertainty, and incompleteness in sensing data on wave reconstruction/prediction:** We develop an approach based on the use of the phase-resolved nonlinear wave reconstruction/prediction to recover the wave information in the shadow of radar measurements and to evaluate the validity, liability, and accuracy of wave reconstruction due to the effects of noise, uncertainty, and incompleteness in sensed data.

- **Modeling of wind input:** To account for wind effects in wave reconstruction/prediction, we develop and validate a first generation model for wind forcing input for direct phase-resolved nonlinear wavefield simulations. In this model, the wind forcing is modeled as a pressure distribution closely correlated to wave slope with the growth rate determined by matching to existing laboratory/field observations.

- **Validation and calibration with field measurement:** We perform a preliminary validation of the developed wave reconstruction capability by applications to realistic ocean waves using radar sensed wave data.

RESULTS

As a preliminary validation of the developed wave reconstruction/prediction capability, we perform an application to realistic ocean environment for which some (WAMOS) radar sensed data and buoy measurements are available. The sea condition is mild with a significant wave height of H_s ~ 3m and a peak wave period of T ~ 6s. We reconstruct the wavefield in a domain of ~1km × 1km based on radar sensed wave data at an instant, say, t=0, and then forecast its evolution in a short period of time, $t \in [0,2T]$. Quantitative comparisons of the predicted phase-resolved wavefield with radar sensed data (not used in reconstruction) and (point) buoy measurement (not used in reconstruction) show the effectiveness of the approach which is quite encouraging although the characterization of liability and resolution of wave prediction still needs to be further assessed.

Figure 1 shows the reconstructed phase-resolved wavefield (at instant t = 0) using the radar inversion data. Apparently, the reconstructed wavefield exhibits all wave details present in the radar sensed data. For independent variation of the accuracy of wave reconstruction/prediction, in figure 2, we make a direct comparison of the time history of wave elevation between the forecasted wavefield and in-situ ASIS buoy measurement (which is not used in wave reconstruction). The comparison indicates that the forecasted wave elevation is in a good agreement with the buoy data in the period of $t \in$[~18, ~30]s, which is ~2T. Outside this period of time, there is little correlation between the forecasted wavefield and the buoy data. Figure 3 compares the surface profile of the forecasted wavefield at time t/T=0.5 with the radar sensed data (which is not used in reconstruction). The discrepancy between them is also shown. It is seen that the forecasted wavefield is in reasonable agreement with the data except in the boundary areas where a significant discrepancy is seen due to the influence of waves outside the computational domain (not considered in reconstruction).

IMPACT/APPLICATIONS

Advances in large-scale nonlinear wave simulations and ocean wave sensing have recently made it possible to obtain phase-resolved high-resolution reconstruction and forecast of nonlinear ocean wavefields based on direct sensing of the waves. Such a capability will significantly improve ocean-surface sensing measurements and deployment, and data assimilation and interpretation, by providing a comprehensive wave-resolved computational framework. Another important potential application of this is to greatly increase the operational envelopes and survivability of naval ships by integration of such capability with ship-motion prediction and control tools.

REFERENCES

1. Wu, G. 2004 Direct simulation and deterministic prediction of large-scale nonlinear ocean wave-field. Ph.D Thesis, Massachusetts Institute of Technology, Cambridge, MA.

PUBLICATIONS

1. Xiao, W., Henry, L., Liu, Y., Hendrickson, K. & Yue, D.K.P. “Ocean Wave Prediction Using Large-Scale Phase-Resolved Computations”, Proceedings of the DoD HPCMP Users Group Conference 2008, June, Seattle, WA.
2. Wu, G., Liu, Y., Kim, M.H. & Yue, D.K.P., 2008 Deterministic reconstruction and forecasting of nonlinear irregular wave fields. *J. of Fluid Mech*. (under review).

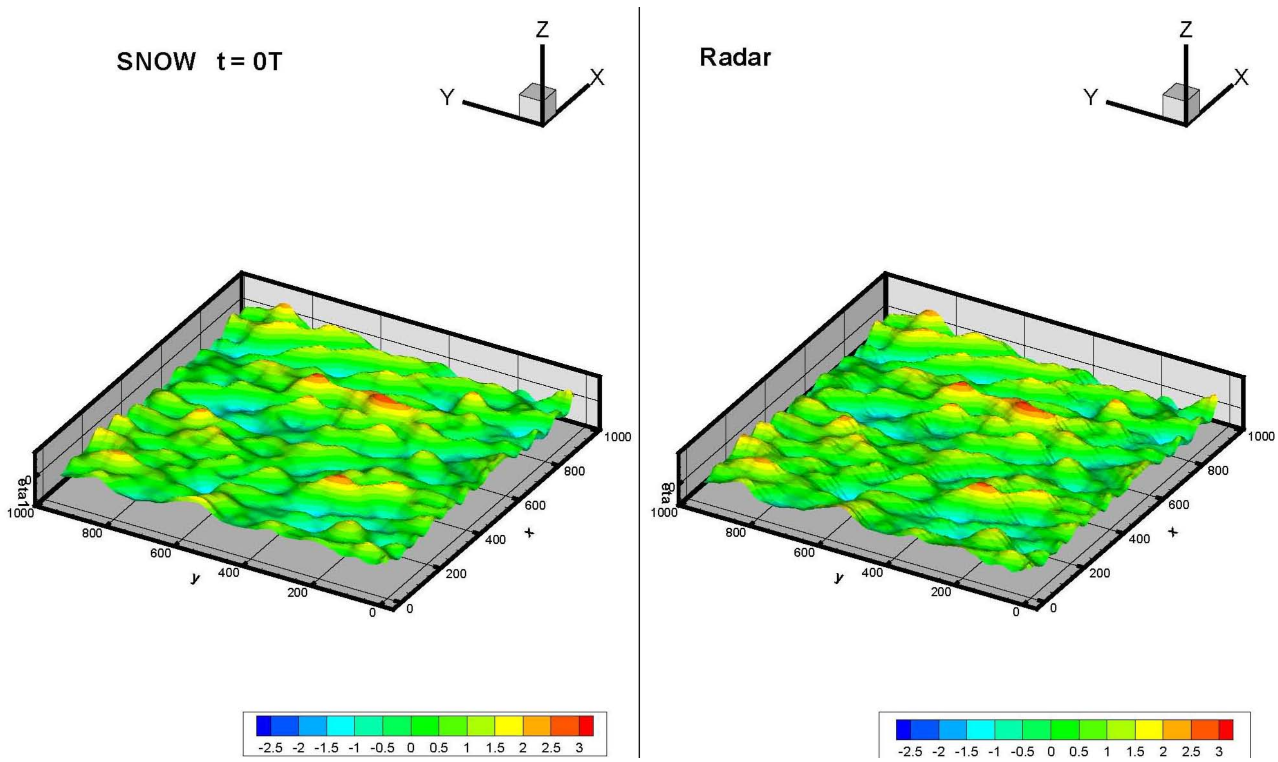


Figure 1: Comparison of reconstructed wavefield (left) and radar sensed wavefield (right). The radar sensed data is assimilated in reconstruction.

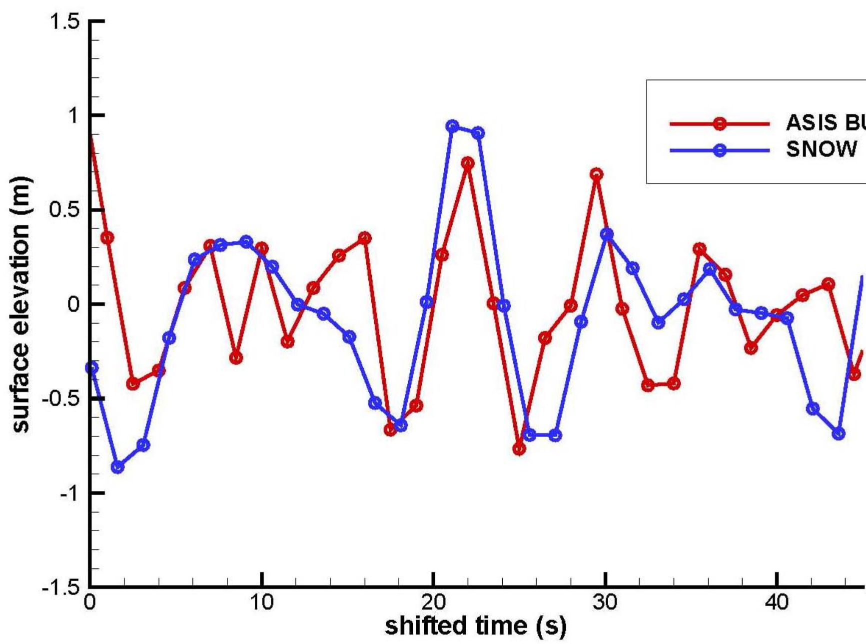
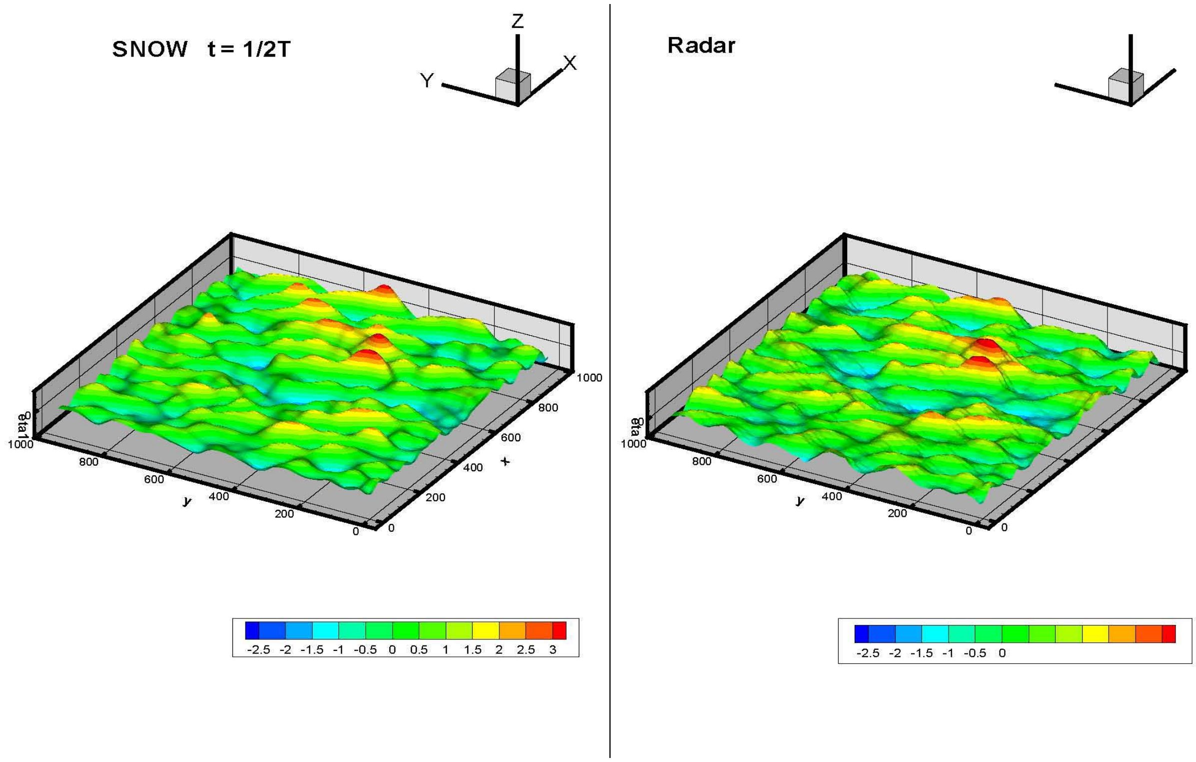
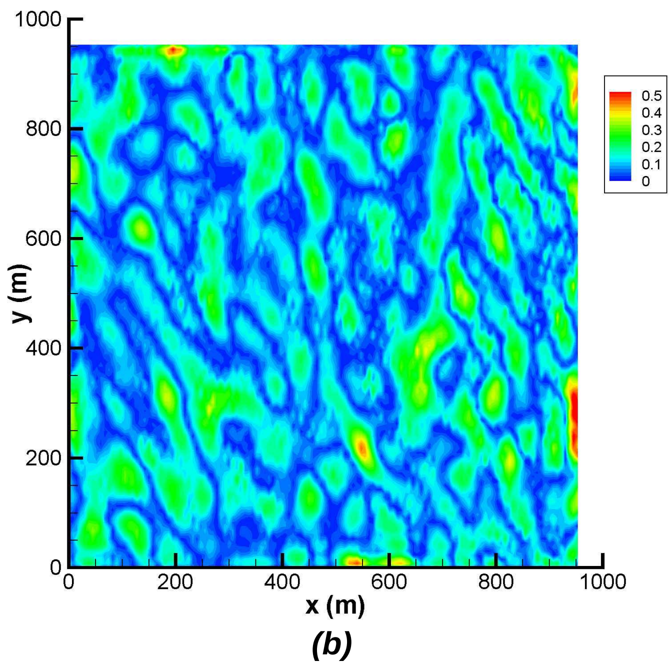


Figure 2: Comparison of the time history of wave elevation between nonlinear wave prediction (blue line) and the ASIS buoy measurement (red line).



(a)



(b)

Figure 3: (a) Comparison of surface wave profiles of the forecasted wavefield (left) and radar sensed data (right) reconstructed wavefield (left) and the radar sensed data (right), at time t/T=0.5; and (b) contour of the normalized error of wave elevation between the forecasted wavefield and the radar sensed data at time t/T=0.5.